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Recently, there has been considerable research into the development and applications of fiber-optic spectroscopic sensors. The large number of recent reviews attest to the widespread interest in this area (1-6). Fiber optics have several advantages over conventional optics; they can easily be miniaturized, and can be used at a remote distance from the laboratory and/or under harsh conditions. Our research group has been active in the area of fiber-optic chemical sensors. In the course of setting up an instrumental system for sensor research, we discovered some unusual luminescence behavior originating in the optical fiber itself. When a pulsed, high-energy, ultraviolet laser beam was coupled into a fused silica fiber, the fiber was seen to glow a bright red color. The color was intense enough to be seen with the naked eye in a well-lit room, and appeared to be uniform along the length of the fiber. We proceeded to study this observed emission. This report summarizes our observations.

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LUMINESCENCE ORIGINATING IN AN OPTICAL FIBER

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Recently, there has been considerable research into the development and applications of fiber-optic spectroscopic sensors. The large number of recent reviews attest to the widespread interest in this area (1-6). Fiber optics have several advantages over conventional optics; they can easily be miniaturized, and can be used at a remote distance from the laboratory and/or under harsh conditions. Our research group has been active in the area of fiber-optic chemical sensors. In the course of setting up an instrumental system for sensor research, we discovered some unusual luminescence behavior originating in the optical fiber itself. When a pulsed, high-energy, ultraviolet laser beam was coupled into a fused silica fiber, the fiber was seen to glow a bright red color. The color was intense enough to be seen with the naked eye in a well-lit room, and appeared to be uniform along the length of the fiber. We proceeded to study this observed emission. This report summarizes our observations.

EXPERIMENTAL

The second-harmonic line (532 nm) of a Quantel International model YG580 Nd:YAG laser was used to pump a Quantel International model TDL50 dye laser. Rhodamine 590 (Exciton) was used as the dye. The dye laser fundamental beam was set at 561 nm, except where noted. The frequency-doubled output, at 280.5 nm, was focused through a 500-mm focal length fused-silica lens (Oriel) into one end of a 600-μm inner diameter fused-silica optical fiber (Galileo Electro-Optics), which was attached to a Newport model LP-1 optic mount. Light which passed through the fiber was focused through a second lens onto the entrance slit of a SPEX model 1680 double monochromator.

For conventional emission measurements, the signal from a Hamamatsu R928 photomultiplier tube, powered to -1000 V by a Pacific Photometric Instruments model 203 negative high-voltage power supply, was sent to a Keithley model 414S picoammeter. The signal was then directed to a MINC 11/23 computer (Digital Equipment Corporation) for data collection and processing. The computer also scanned the double monochromator.

Luminescence lifetime measurements were obtained with the instrument shown in Figure 1. The output of the R928 photomultiplier tube was sent to a Stanford Research Systems model SR250 gated integrator and boxcar averager. The boxcar averager was triggered by the Q-switch output of the Nd:YAG laser. The boxcar-averaged output was sent to a strip chart recorder (Heath model SR-405). The decay curves thus obtained were digitized by using a Tektronix model 4051 computer with a Tektronix interactive digital plotter. Decay curves were then fitted to a single exponential curve:

$$Y = A \exp(BX) \qquad \text{(Eqn. 1)}$$

where Y is the observed intensity and X is elapsed time. The value of B is used to calculate the luminescence lifetime, taking advantage of the following relationship:

$$dt = I_o \exp(-t/\tau) \qquad \text{(Eqn. 2)}$$

where τ is the lifetime of luminescence and $-1/\tau = B$ in equation 1.

RESULTS AND DISCUSSION

The emission spectrum from the fiber is shown in Figure 2. The sharp peak at 561 nm is background from scatter of the dye-laser fundamental line. Luminescence is broad and covers the range from approximately 610 to 700 nm, with a maximum at 650 nm. The observed

emission is red-shifted by more than 350 nm from the excitation wavelength (280.5 nm). This emission is not observed if the dye laser fundamental beam (561 nm) is used for excitation. In addition, this emission is not seen when a Spectra-Physics model 171 argon-ion laser is used as the excitation source in the visible or near-UV regions.

Slight changes in the excitation wavelength do not change the emission spectrum. The dye laser fundamental wavelength was varied from 561.00 nm to 569.50 nm, corresponding to a 280.50 nm to 284.75 nm excitation wavelength. No difference in the emission spectrum was observed, indicating that it is a luminescence phenomenon and not due to scattering.

This phenomenon is directly proportional to laser power, as shown in Figure 3, over the tested range of 5 to 32 mW average power. Thus, it cannot be attributed to nonlinear effects.

Figure 4 shows a typical decay curve for the fiber luminescence, taken from a digitized version of the strip-chart recorder output. The line drawn through the points is a single exponential curve fitted to the data using Eqn. 1. The luminescence lifetime calculated from this decay curve is 1.77 μs. Neither varying the laser average power from 10 to 21 mW, nor varying the monitored emission wavelength had an appreciable effect on the calculated lifetime of luminescence. Fluorescence lifetimes are generally on the order of nanoseconds, whereas phosphorescence lifetimes are on the order of milliseconds. Thus, the observed emission phenomenon is not easily characterized as either fluorescence or phosphorescence.

Removing the fiber optic's cladding, by soaking it in hot, concentrated sulfuric acid, results in elimination of the luminescence

phenomenon. Thus, the emission is due either to the cladding or to an interaction between the fused silica fiber core and the cladding. It is interesting to note that the cladding is not a single polymer, but a mixture of several substances. Unfortunately the composition of the cladding material, which Galileo Electro-Optics is now using on their UV-grade optical fiber, is proprietary and cannot therefore be evaluated directly. Fortunately, the observed emission is not a problem for many applications of this optical fiber to chemical sensors. The emission is so greatly red-shifted that it does not complicate many fluorescence measurements.

In short, luminescence from a fused-silica optical fiber is observed upon excitation with high-power laser radiation at a wavelength af approximately 280 nm. The emission is broad and centered at 650 nm. Its decay follows a single-exponential pattern, and yields a lifetime of luminescence of approximately 1.7 μs. The intensity of the emission is proportional to the average power of the laser beam, and emission ceases when the cladding is removed from the fiber.

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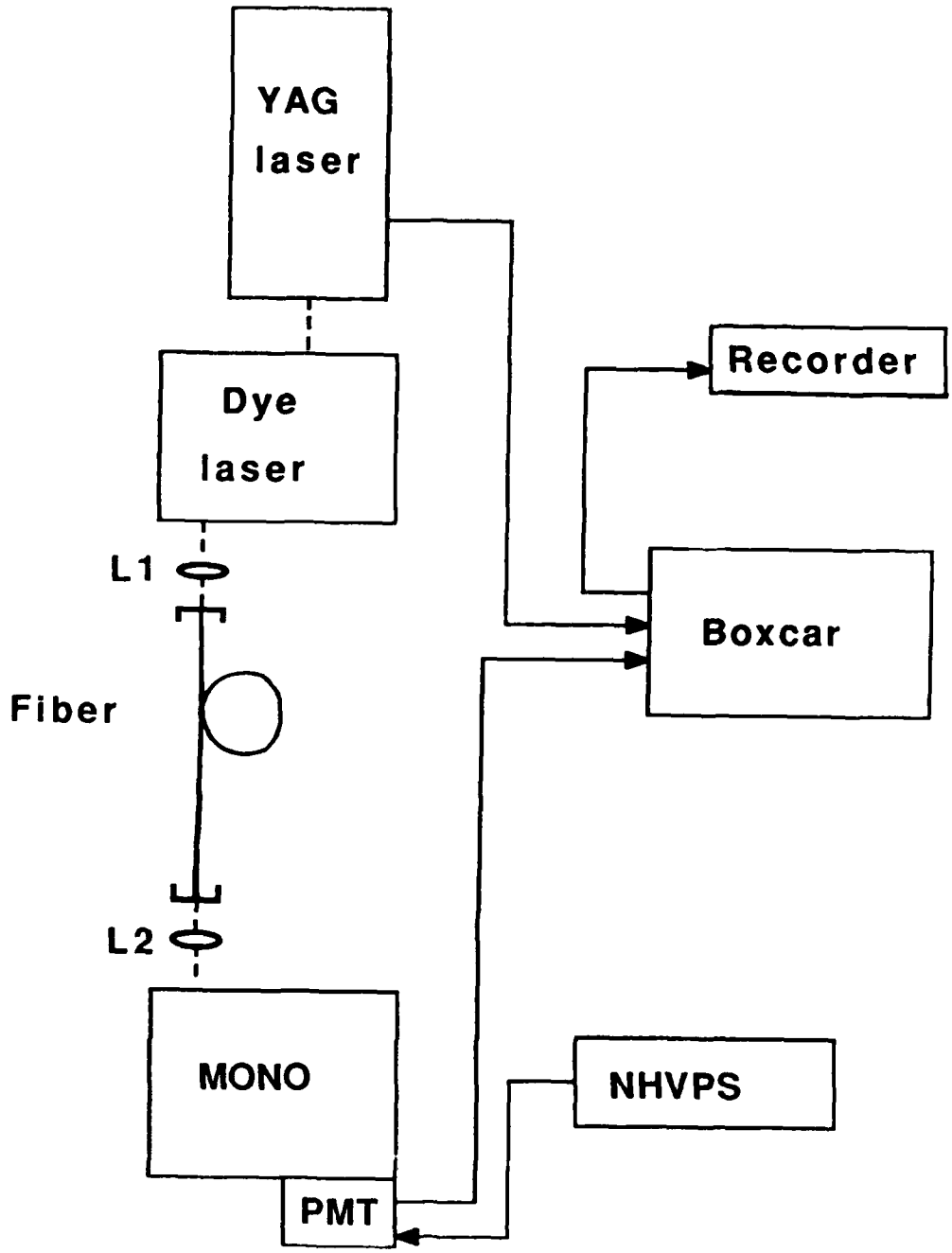
FIGURE CAPTIONS

Figure 1: Block diagram of experimental system for luminescence decay measurements. L1 and L2 are lenses, MONO is a double monochromator, PMT is a photomultiplier tube, and NHVPS is the PMT high-voltage power supply.

Figure 2: Luminescence spectrum of the fiber. Excitation wavelength is 280.5 nm.

Figure 3: Dependence of emission from fiber on radiant power in the excitation beam. Excitation wavelength: 280.5 nm; emission wavelength: 650.0 nm; laser repetition rate: 20 Hz.

Figure 4: Luminescence decay curve. Excitation wavelength: 250.0 nm; emission wavelength: 640.0 nm; average laser power: 21 mW. Asterisks indicate data points digitized from strip chart recording. Line drawn through points is a fit to a single exponential function.


YAG
laser
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L1
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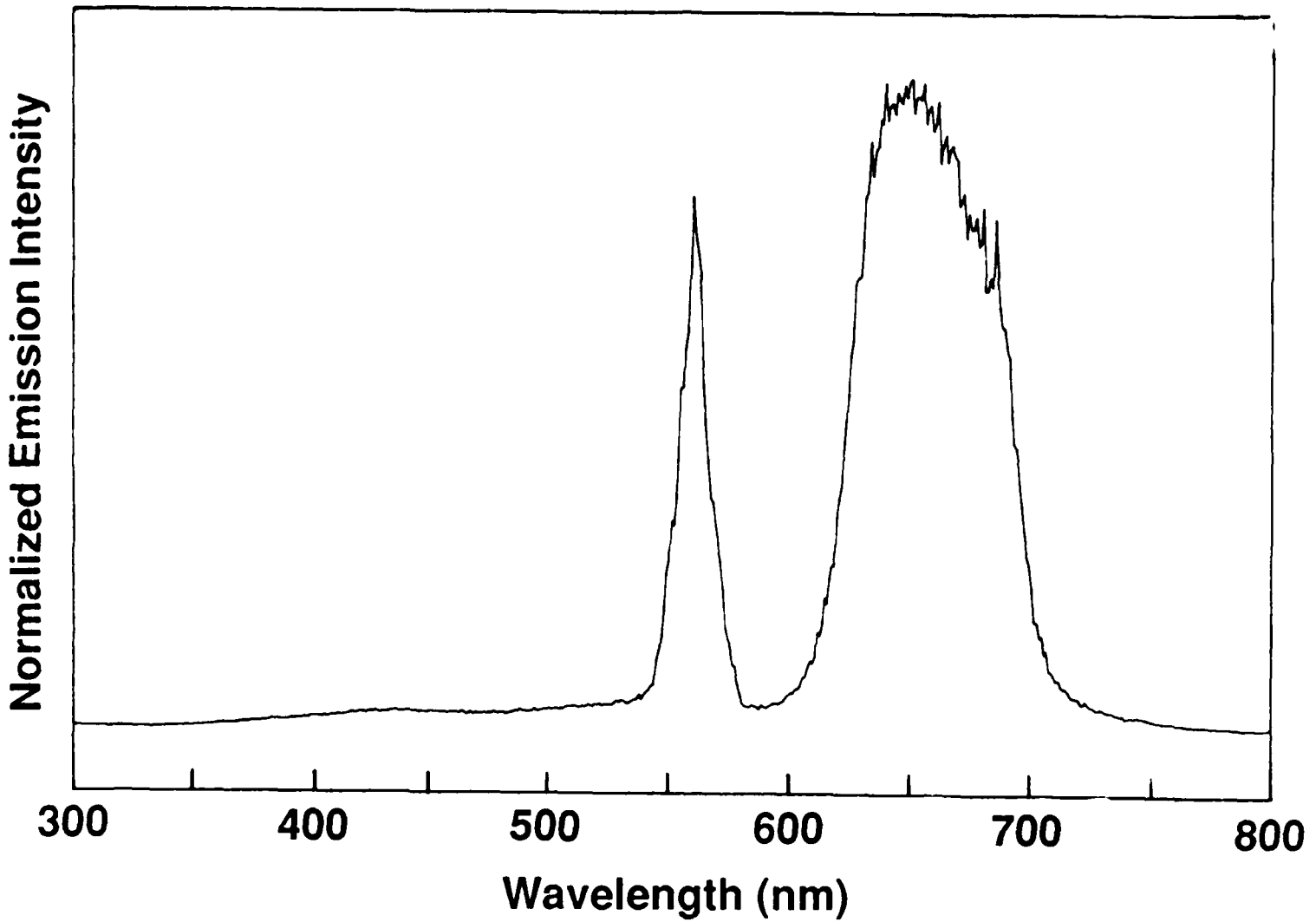
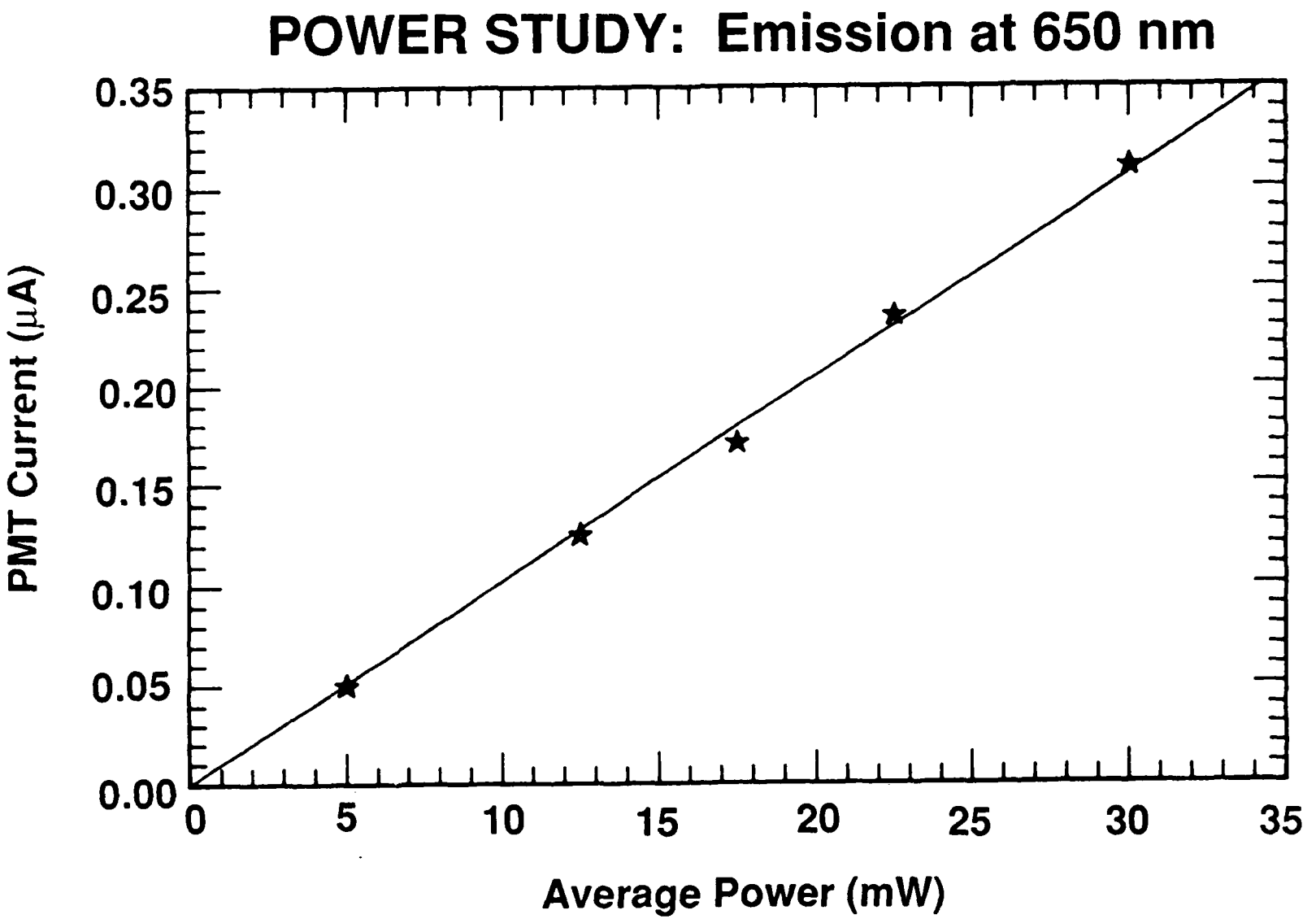
MONO
PMT
Recorder
Boxcar
NHVPS

EMISSION SPECTRUM




POWER STUDY: Emission at 650 nm
PMT Current (μA)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
25
30
35
Average Power (mW)

Emission Decay Curve